Laser Ion Source Development for ISOL Systems at RIA

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1. Introduction

The goal of this R&D effort is to develop a prototype next-generation resonant laser ion source (LIS) with demonstrated potential for providing high selectivity and efficiency as required for research at the future Rare Isotope Accelerator (RIA) with ISOL-generated radioactive ion beams. The development of reliable, rugged and compact laser systems that are easy to operate will also be crucial for potential applications at RIA. Therefore, all-solid-state tunable Ti:Sapphire lasers will be investigated as the principal laser system for the prototype LIS. In FY04, we have focused on conducting a pilot LIS experiment to demonstrate resonant photoionization of selected atomic species using three tunable Ti:Sapphire lasers at the off-line Ion Source Test Facility (ISTF) of HRIBF. To accomplish this goal, a collaboration between the HRIBF, the Atomic Physics Group of the ORNL Physics Division, and the research group led by Dr. Klaus Wendt of the University of Mainz, Germany, has been established.

2. Objectives

We set the following objectives for FY04:

1) Identify several atomic species to serve as efficiency and selectivity benchmarks for the LIS system,
2) Investigate the ionization schemes for the selected atomic species,
3) Design and construct a hot-cavity LIS,
4) Reconfigure the ISTF and set up the hot-cavity LIS for use with Ti:Sapphire lasers,
5) Produce laser- ionized beams of the selected atomic species at HRIBF.

The results obtained from the above pilot LIS experiment will be used to specify the laser and ion source requirements for the follow-up work, and to optimize the required laser hardware and ion source designs. To date, most of these objectives have been accomplished. Our progress is summarized below.

2.1 Atomic species for the pilot LIS experiment

The elements Sn, Ni and Ge have been chosen for the pilot LIS experiment because they are among the important radioactive ion beams for studies in nuclear structure and nuclear astrophysics, and for following additional considerations. Tin is chosen as the primary benchmark species for efficiency and selectivity of the LIS system, as it provides a broad spectrum of isotopic abundances and has been studied using different laser systems at ISOLDE and the University of Mainz.

2.2 Ionization scheme

Although ionization schemes for many atomic species have been tested or proposed, most of these ionization schemes are only useful with dye lasers. Extensive R&D effort will be needed to study new ionization schemes accessible with Ti:Sapphire lasers. The research work in this area has been mainly carried out at the University of Mainz led by Dr. Wendt. So far 10 elements have been investigated, while another 60 are expected to be accessible using fundamental, doubled and tripled Ti:Sapphire laser wavelengths. The first resonant laser ionization of Sn from a LIS using Ti:Sapphire lasers was successfully obtained with an overall efficiency of ~7% by the Mainz group at CERN in May 2004. For preparation of the joint effort, different ionization schemes for Ge as well as Ni have been investigated using Ti:Sapphire lasers at the University of Mainz.

2.3 Hot-cavity laser ion source

A hot-cavity type laser ion source has been designed and constructed at the HRIBF for the LIS experiment. A schematic view of the ion source is shown in Fig. 1. It consists of a tubular Ta cavity of 3 mm inner diameter and 30 mm in length, connected to either a Ta or graphite target material reservoir via a Ta vapor transport tube. The tantalum cavity can be resistively heated to around 2000 °C, while the target reservoir temperature can be varied by an independent heater. The ion source can fit in the standard housing for the ion sources used at the HRIBF and has been tested and characterized operating as a surface ionization source using Cs and other alkali elements.

2.4 Ti:Sapphire laser system

A complete hot-cavity LIS system with three tunable Ti:Sapphire lasers has been set up at the off-line ISTF of the HRIBF. The ISTF has been reconfigured and updated for the LIS experiment. The Ti:Sapphire lasers have been developed, provided and are operated by the Mainz group. They are pumped by a commercial frequency-doubled Nd:YAG laser operating at 10 kHz repetition rate with a maximum of 60 W average power at 532 nm. (The YAG laser was leased from the Photonics Industries International, Inc., with the provision for a later purchase at a discounted price.) With 2nd and 3rd harmonic generation capabilities, the laser system can provide several two- and three-photon ionization schemes for the selected atomic species. Figure 2 shows a picture of the Ti:Sapphire laser system in operation at HRIBF.

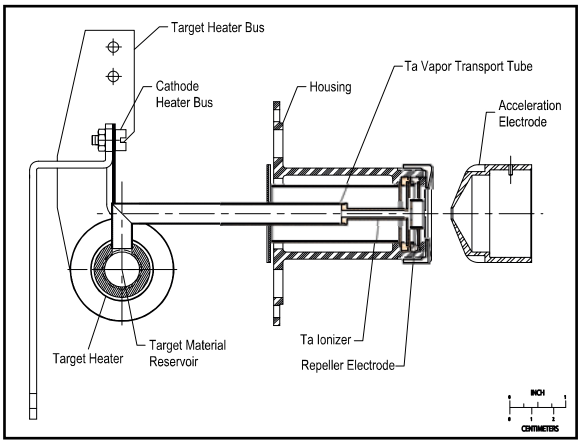

Figure 1. Schematic of the hot-cavity ion source with a ϕ3 mm x 30mm Ta cavity and a repeller electrode. Atomic species of interest effuse from the heated target reservoir into the hot Ta cavity to be irradiated by photons.

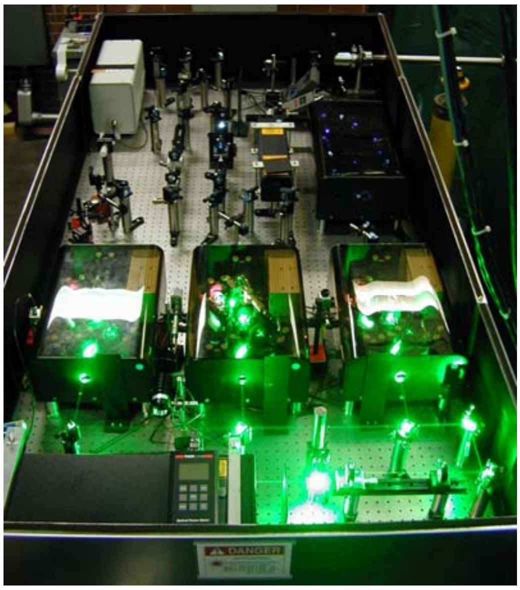

Figure 2. The Ti:Sapphire laser system from the University of Mainz in operation at the HRIBF.

2.5 Preliminary results of the pilot LIS experiment

Experiments on resonant laser ionization of Sn, Ni and Ge for ion beam production with the Ti:Sapphire laser based hot-cavity LIS are now underway at the HRIBF ISTF. Laser generated Sn, Ni and Ge ion beams have been successfully obtained. Figure 3 shows the mass spectrum of Sn ions ionized by the laser beams and the surface-ionized ions when the lasers are turned off. The temperature of the hot-cavity was estimated to be about 1700°C. All the

Sn ion beams were produced by laser ionization with no surface ionized Sn ions observed. The three-photon ionization scheme used is shown in Fig. 3. Each excitation step was saturated with sufficient laser power and more than 100 nA of ^{120}Sn ion current was measured. Overall efficiency measurements of the LIS for Sn are in progress. Further experiments on resonant ionization of Ni and Ge atoms are currently underway, with special interest in exploring third-step ionization schemes utilizing a variety of autoionizing and available Rydberg states. The operation of the hot-cavity ion source and laser system has been very stable and reliable.

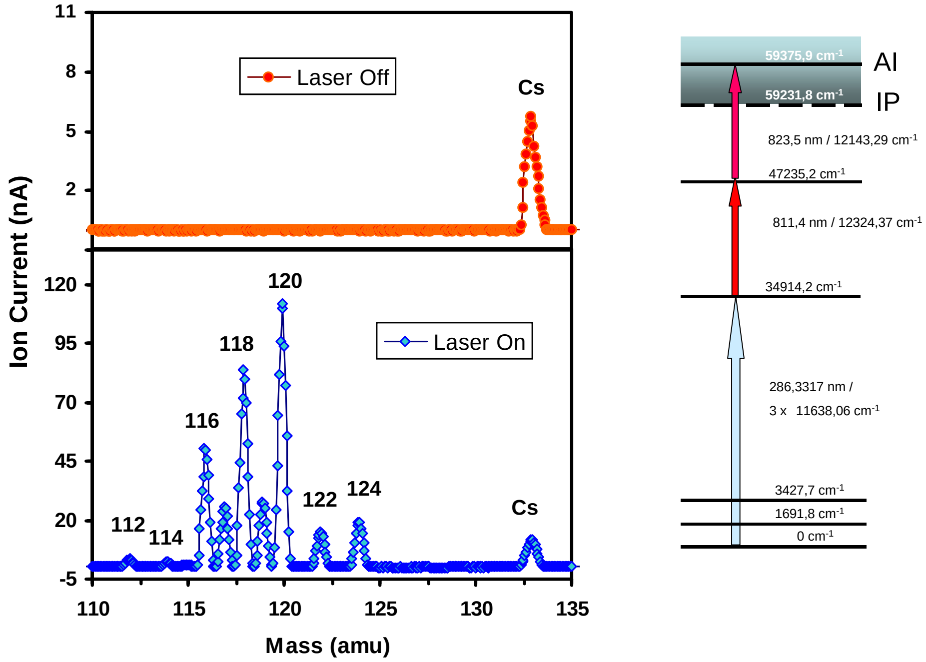

Figure 3. Mass spectra measured with lasers off (upper left) and lasers on (bottom left). All the Sn ions observed were produced by the resonant photoionization process. The ionization scheme for Sn is shown on the right.

3. Summary of expenditures

Total funding for this project in FY2004 has amounted to \$140,000, with initial funding received in March 2004. Expenditures through September 2004 total \$98,000 as summarized in table 1. Total expenditures to date include \$76,000 for materials, \$10,000 for support of ORNL Atomic Physics staff (0.1 FTE for six months) and \$12,100 to provide travel and per-diem expenses for the Mainz group (Dr. Wendt and three students). A total of \$41,700 remains to support activities on this project between September 2004 and the award of funds for 2005. These funds are essentially all committed and will be spent before January 2005.

Table 1. Cost to date summary

Cost element	Cost through 9/2004
Pump laser (leased)	$39,000
Misc. optical and safety equipment	16,000
Ion source and ion beam equipment	21,200
Mainz group support	12,100
ORNL (non-KB) staff	10,000
Total	**$98,300**

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